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## ELECTRICAL TRANSMISSION SYSTEM

The present invention relates to the transmission of electrical energy between different parts of a structure – including in particular underground, sub-sea or sub-seabed structures. The invention is more particularly, though not exclusively, concerned with transmission along oil and gas pipelines, and especially in wells.

Oil and gas wells conventionally utilise substantial lengths of steel pipework during drilling/perforating operations and, during production, for conveyance of the oil or gas to the surface. They are also typically equipped with perforators, pumps, valves, actuators, flowmeters, strain gauges, temperature and pressure monitors and/or other downhole instrumentation at the base of the well, and optionally at other selected positions along the pipework, requiring the transmission of electrical power and/or data signals from/to the surface. The use of conventional discrete electrical cabling for this purpose is problematical, however. It has to be attached to the well pipework at a large number of separate, carefully chosen locations in an effort to minimise the likelihood of breakage or damage to the conductors or their insulation. Placement and protection of discrete cabling is time consuming and does not always avoid the problems of breakage or damage.

The present invention seeks to avoid these drawbacks and in one aspect resides in a structure of electrically conductive material provided with means for the transmission of electrical energy between spaced locations along the structure, comprising a first layer of electrically insulative material deposited on the structure, one or more electrically conductive tracks deposited on said first layer, and a second layer of electrically insulative material deposited over said electrically conductive track(s), said first and second electrically insulative layers each comprising a ceramic material deposited by a thermal spray process.

The invention also resides in a method of providing a structure of electrically conductive material with means for the transmission of electrical energy between spaced locations along the structure which comprises the steps of: depositing a first layer of electrically insulative material on the structure; depositing one or more electrically conductive tracks on said first layer; and depositing a second layer of electrically insulative material over said electrically conductive track(s); said first and second electrically insulative layers each comprising a ceramic material and being deposited by a thermal spray process.

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By thus providing insulated conductors integral with the structure the use of separate cabling for the transmission of power or data signals between different locations on the structure may be avoided. The compositions of the ceramic insulators can be chosen to provide high electrical resistivity coupled with mechanical durability and resistance to corrosion under a range of demanding service conditions, and thermal spraying provides an effective mechanism for the deposition of such materials in consistent high quality coatings.

By "thermal spray process" we mean a process in which particles of the material to be deposited are heated to a molten or softened condition and projected in a stream towards the substrate on which the respective layer is to be formed. Suitable thermal spray processes for use in this invention include so-called plasma spraying and high velocity oxy fuel (HVOF) spraying.

The ceramic material forming the aforesaid first and second electrically insulative layers may comprise aluminium oxide with a minor proportion of titanium oxide, the latter typically in a proportion of 2-45% by weight. More particularly the proportion of titanium oxide may be in the range 10-15% by weight in the first insulative layer and 35-45% by weight in the second insulative layer.

These and other features of the invention will now be more particularly described, by way of example only, with reference to the accompanying schematic drawings in which:-

Figure 1 is a cross section through part of a structure to which the invention may be applied, namely an oil well installation;

Figure 2 is transverse cross section through part of the pipe string illustrated in Figure 1;

Figure 3 is an end/side view of part of the pipe string illustrated in Figure 1;

Figure 4 illustrates an example of deposition of material by plasma spraying; and

Figure 5 illustrates an example of deposition of material by high velocity oxy fuel spraying.

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Figure 1 is a simplified cross section through part of a production oil well installation to which the invention may be applied. It comprises a borehole through earth formation 1 lined with a steel casing 2. Running down through the casing 2 from the surface to the oil reservoir below is a steel pipe string 3 assembled from successive sections 3A joined end to end, and through which oil is conveyed to the surface. Depending on the construction and location of the installation the annulus 4 between the pipe string 3 and casing 2 may contain, at different depths, earth, oil or water, or cement or other packers to prevent displacement of the pipe string in the borehole. Although not shown in the Figure, various equipment and instrumentation associated with the operation of the well will be located at its base, and other instrumentation for monitoring the condition of the pipe string 3 may be located at various positions along its length, to which electrical power must be transmitted from the surface and/or from which electrical data signals must be transmitted to the surface. For this purpose each length of pipe 3A is provided with a multilayer coating as will now be described with reference to Figures 2 and 3.

Figure 2 is a transverse cross section through a length of pipe 3A and its applied coating, not to scale, and Figure 3 is an end/side view of the structure of Figure 2, again not to scale, and with the outer coating layer partially omitted for ease of illustration.

A first layer 5 of electrically insulative material is deposited along the length of the outer surface of the pipe 3A over part (as shown), or possibly all, of its circumference. A series of parallel tracks 6 of electrically conductive material are then deposited on the insulative layer 5. Finally, a second layer 7 of electrically insulative material is deposited over the tracks 6 and on to the layer 5 between and around the tracks. In use the tracks 6 serve for the transmission of electrical energy along the length of the pipe to/from the various downhole equipment and/or instrumentation. The pipe 3A may itself serve as an additional transmission path. The provision of multiple tracks 6 enables a plurality of separate channels to be defined to a range of different equipment and/or instrumentation types, and useful redundancy in the event that individual tracks become damaged.

Layer 5 serves to electrically insulate the tracks 6 from the pipe 3A and is composed of a ceramic material, typically 0.1 to 0.3mm thick. Layer 7 serves to electrically insulate the tracks 6 from the environment or structure external to the pipe and to provide physical protection for the conductive tracks during handling, installation and use. It is also composed of a ceramic material, with a thickness of typically 0.1 to 0.3mm above the tracks 6. The compositions of the layers 5 and 7 may be the same or different, as layer

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5 will be selected primarily for its electrical resistivity while layer 7 is selected also for mechanical and chemical durability under the conditions likely to prevail in the intended service of the pipe. In one example which has been found to combine good electrical isolation with mechanical robustness and resistance to oil and seawater the ceramic composition is predominantly alumina ( $\text{Al}_2\text{O}_3$ ) blended with a minor proportion of titania ( $\text{TiO}_2$ ). The proportion of titania in the inner insulative layer 5 may be in the region of 13% by weight, while for enhanced abrasion resistance in the outer insulative layer this may be increased to the region of 40%. The conductors 6 are preferably of high purity copper, typically 0.25mm thick.

The materials 5, 6 and 7 are each applied by a thermal spray process, such as plasma spraying or high velocity oxy fuel (HVOF) spraying, with the use of suitable masks to define the bounds of the conductive tracks, and the spraying head(s) being traversed relative to the pipe 3A to achieve the required area of coverage and with sufficient passes to build up the required thicknesses of deposited material. Although not shown, the tracks 6 will be provided with terminations at each end of the pipe 3A through which they can be electrically connected to the corresponding tracks on the next pipe length, and terminals will also be provided where required for connection to the respective downhole equipment/instrumentation. This may be accomplished through selective masking of the tracks during application of the layer 7.

An example of one form of apparatus for use in deposition of the materials 5, 6 or 7 by plasma spraying is illustrated schematically in Figure 4. The spraying head comprises an anode 41 and cathode 42, surrounded by a cooling water jacket 43. The anode is shaped to define a nozzle 44 leading from an annular gas supply duct 45 which surrounds the cathode 42. Plasma gas such as argon, nitrogen, hydrogen or helium is supplied along the duct 45 and the plasma is initiated by a high voltage DC arc between the cathode and anode. The resistance heating from the arc causes the gas to reach extreme temperatures and dissociate to form a plasma, which exits the nozzle 44 as a neutral flame. The plasma stabilises with the arc between cathode and anode becoming stretched along the length of the nozzle by a thermal pinch effect; cold non-conductive gas around the surface of the water-cooled anode constricts the flame, raising its temperature and velocity. Powder of the material to form the layer 5, 6 or 7 is injected into the flame through radial ports 46 beyond the nozzle 44, where it is rapidly heated and accelerated to a high velocity. The resultant stream 47 of molten or softened particles is directed against the applicable substrate surface 48 (representing the pipe 3A

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and/or earlier-deposited layers 5, 6 as the case may be), where the particles rapidly cool and coalesce to form the respective coating.

An example of one form of apparatus for use in deposition of the materials 5, 6 or 7 by high velocity oxy fuel spraying is illustrated schematically in Figure 5. The spraying head comprises a combustion casing 51 shaped to define a nozzle 52 leading from three coaxial supply ducts 53, 54 and 55. Powder of the material to form the layer 5, 6 or 7 is fed at high pressure in nitrogen carrier gas through the central duct 53; a mixture of fuel gas (e.g. propane) and oxygen is fed at high pressure through a surrounding annular duct 54; and compressed air is fed through the outer annular duct 55. The oxy fuel mixture is ignited in the vicinity of the nozzle 52 to produce a high temperature, high velocity flame. The compressed air from duct 55 pinches and accelerates the flame and cools the surrounding structure. The powder from duct 53 is fed into the flame where it is rapidly heated, the resultant stream 56 of molten or softened particles being directed against the applicable substrate surface 57 (representing the pipe 3A and/or earlier-deposited layers 5, 6 as the case may be), where the particles rapidly cool and coalesce to form the respective coating.